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A BRAILLE INTERFACE TO THE TEXAS INSTRUMENTS SR-52 PROGRAMMABLE CALCULATOR

C. P. JANOTA

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September 21, 1976
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POCKET CALCULATOR
PROGRAMMABLE CALCULATOR
TEXAS INSTRUMENTS CALCULATOR

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Texas Instruments SR-52 programmable pocket calculator has been interfaced with a tactual display for use by a blind graduate assistant. The interacing uses simple, readily available series 4000 CMOS circuitry to convert the contents of the calculator's visual display to a self-scanned Braille output. The rate of character display is user controlled. Provisions are included to display the mantissa and exponent sign and calculator display mode. Blanks in the output are elminiated.

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ABSTRACT

(U) The Texas Instruments SR-52 programmable pocket calculator has been interfaced with a tactual display for use by a blind graduate assistant. The interfacing uses simple, readily available series 4000 CMOS circuitry to convert the contents of the calculator's visual display to a self-scanned Braille output. The rate of character display is user controlled. Provisions are included to display the mantissa and exponent sign and calculator display mode. Blanks in the output are eliminated.

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1. General Interface Description

To provide blind engineers and scientists with the use of a card programmable scientific calculator, an interface has been built to the Texas Instruments SR-52 instrument. Circuitry using commercially available devices simply and cheaply converts the contents of the calculator's optical display to a self-scanned, four-dot Braille tactual output.

The SR-52 calculator was chosen because of its powerful instruction set, magnetic card programmability, and its keyboard design. For ease of operation by blind users, a keyboard such as that of the SR-52 with uniformly spaced columns and rows of keys with positive tactual feedback is preferred. Also, the connector for use with the PC-100 printer makes available buffered control signals which simplify the interfacing.

In this design, the necessary segment drive and timing signals are brought out through a small connector on the side of the calculator (Figure 1). These changes in no way impair the utility of the instrument to sighted users, and it may still be used in the printer cradle without restriction.

For use by the blind, the calculator (on battery power or with charger attached) is mounted in a clamp atop the interface circuitry and connected via the connector on the side. Data, instructions, and programs are entered in the usual manner. On command, a Braille display sequence is initiated by the user. The contents of the optical display are output sequentially at a selectable rate to a tactual display using pins which are raised to represent the corresponding numeric data. Special provisions are made for the output of signs and for decimal point indication.

Five drive lines for the calculator's seven segment display (S_A, S_B, S_E, S_G, S_F) are sufficient to identify the numeric data. These five lines are decoded in a programmable read only memory (PROM) to the four Braille display

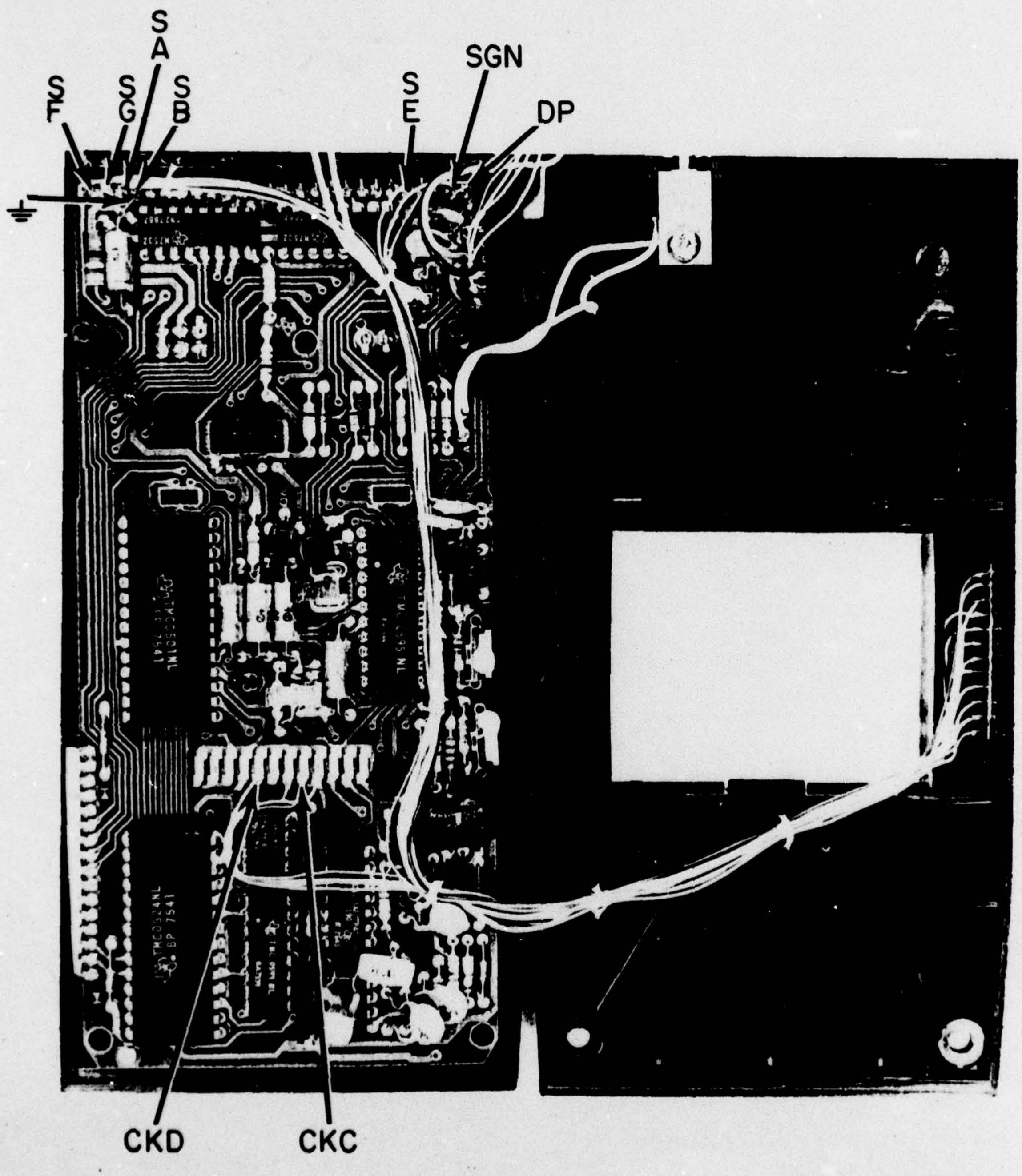

Figure 1. View of SR-52 Calculator Showing Wiring Additions (U)

control signals. Although the display contents and commands are available at the SR-52's printer connector, these data are in a complex bit serial form which is difficult to decode. The segment drive line voltages require the use of level conversion, but are otherwise simply decoded in parallel. Four dots (2, 3, 5, 6) of the complete six dot Braille format are sufficient to output numeric data as well as the minus sign and certain needed punctuation.

In the calculator, numeric character data is sequentially applied to the segment drive lines. The character position is determined by a character strobe applied to the proper display position. A display cycle lasts about 1.3 msec. and consists of 16 character times C_0 - C_{15} of which C_0 and C_1 are never used to display characters. The character positions are strobed from most to least significant with exponents following the least significant mantissa character immediately. A clock pulse CkD occurs at the beginning of a display cycle, and another pulse CkC occurs at the beginning of each character time. These signals are available at the calculator's printer interface connector.

The key to the interfacing lies in synchronizing the storage of the correct Braille control line data when the character position of interest is being strobed on the optical display. This is accomplished by using two, four-bit counters; one contains the instantaneous optical display character position, and another the Braille cell sequence count. The latter counter is clocked by a local oscillator (555 timer) at a controllable rate from about 1/2 second per character to upward of 2 seconds per character. A four-bit magnitude comparator serves to detect coincidence. The output of the PROM is stored in a latch as a result of an equality in the comparator (Figure 2).

The output of the latch directly controls the turn on of drive transistors which activate relays to output the data. The relays are modified to lift the pins used for tactual display. These relays, with associated drive transistors,

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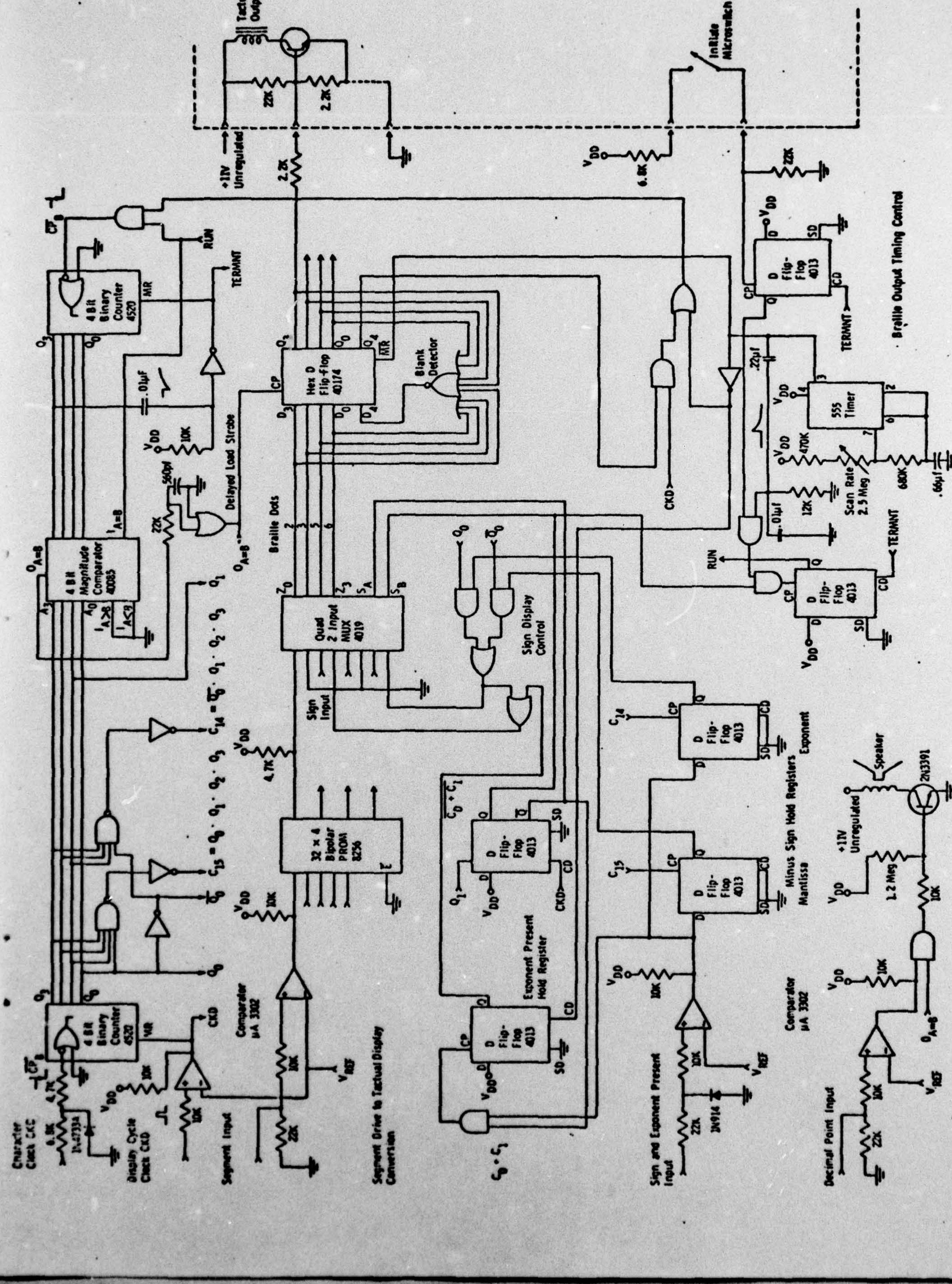

Figure 2. Simplified Schematic Diagram of SR-52 to Tactual Interface (U)

are housed in a separate unit cabled to the interface. A microswitch is collocated with the output and serves to start the sequence. The display sequence is terminated after 16 character positions are output.

Decimal point indication is done by using the logic AND of the display decimal point pulse and the output of the comparator to directly control current through a small speaker's coil. A sufficiently loud tone occurs in coincidence with the character with which the decimal point is associated. Tactual display of the decimal point would have required adding another relay to produce a double cell output (or one non-standard one) or added circuitry to add a display time period which does not occur in the calculator.

The most bothersome aspect of the interface is the need to display the mantissa and exponent signs and to distinguish between floating point and scientific notation. In the SR-52, the signs are not in common with other segments used to output numeric data. Also, the signs are output during character times C_{14}, C_{15} in coincidence with the exponent digits (when present). The sign data is saved in flip-flops by decoded count states of the fast counter. Also, a pulse on the sign data line occurs at character time C_1 whenever the calculator display includes exponents. This state is also saved. During output, Braille cell times 0 and 1 are used for displaying the sign data in two formats depending on the presence of an exponent. When there is none, either a blank or minus sign (Braillė dots 3 and 6) is output to correspond to the mantissa sign. For scientific notation, two signs are always output with the mantissa sign first. A positive sign normally requires a full six dot Braille cell, but is replaced in this application with an apostrophe (dot 3 only). When an apostrophe or two minus signs occur at the beginning, the user knows to interpret the last two digits as the exponent.

To reduce the time to complete a display cycle, the slow counter is advanced at a much higher rate whenever a blank display character occurs. This feature, coupled with the use of format control in the calculator, allows rapid interrogation of the results of computations to accuracies consistent with the problem. The switch to start the sequence is buffered with a flip-flop to insure that all character display times are of equal duration.

The circuit was implemented using primarily CMOS series 4000 logic to reduce power supply requirements to the point where a single voltage regulator chip (μA78MG) could be used to power all 17 integrated circuits. The PROM, however, is a bipolar 32x8 one chosen to match the application (32x4 bits). The same PROM was also programmed to allow for BCD and 1-2-2-4 code to Braille conversion useful in interfacing to counters and digital volt-meters. Segment drive lines are buffered using μA775 quad comparators and a reference voltage of about one volt. An eleven-volt unregulated supply provides ample current through the relays for reliable reading of pin position.

The SR-52 to Braille interface has been demonstrated with blind users. It is easily mastered by anyone proficient in reading Braille and is quite fast with a bit of practice. By notching the edges of the magnetic programming cards (for identification), the blind user can load programs, execute them, and write and debug new ones.

In addition, the interface concept, in that it is a minimal impact one on the calculator, is useful for driving other displays or communications lines. It is a simple means, for example, of interfacing this type of instrument with a speech synthesizer for a "talking" scientific calculator (1). In that respect, it has an advantage over other systems for voice output which have been tied intimately tc limited capability calculator chip sets. To allow

input from the calculator to a serial link such as the RS232C, the PROM would be coded with the ASC II information and additional storage registers added.

In quantity, most of the logic, ROM storage, counters, etc. could be implemented in a single personalized logic array to reduce the component count significantly.

2. Detailed Circuit Description

Figure 3 consists of a simplified schematic diagram in which gates and other circuit components are numbered for easy reference. The detailed circuit description which follows refers to these elements and traces the operation of the circuits to perform segment data to Braille conversion, to synchronize the storage of the Braille control signals, to generate an audio indication of the decimal position, and to handle the storage and display of signs and calculator display format.

The segment drive signals occur at a voltage in respect to the calculator battery negative terminal (system ground) of about +2 volts when segments are illuminated. When dark, the drive lines exhibit a high impedance and normally are at an indeterminate voltage level. In the interface, these lines are terminated with a pull-down resistor (R_1 - R_5) insuring a voltage very near 0 volts in the unilluminated state.

Low voltage to interface voltage level (+5.5 volts nominal) conversion is accomplished by voltage comparators (G_1 - G_5) with a reference voltage of +1.05 volts. Although these gates normally have a high input impedance, series resistors (R_6 - R_{10}) are used to insure minimal calculator battery drain when power in the interface is off. The unpowered gate input impedance is much less and could lead to excessive battery drain.

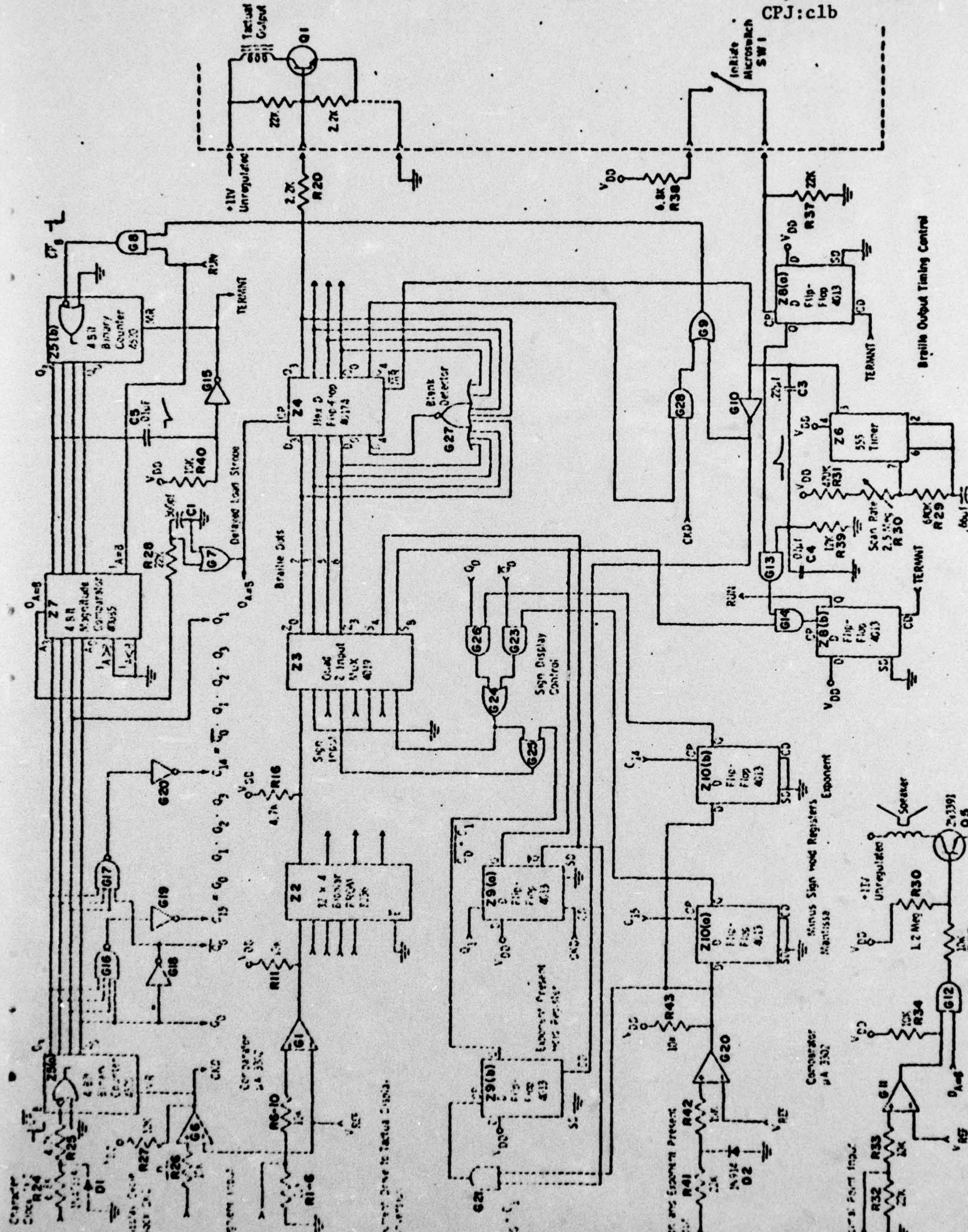

Figure 3. Simplified Schematic Diagram with Components Identified (See Text for Circuit Function Explanation) (U)

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The voltage comparator gates have uncommitted collector outputs with a 20mA current sinking capability adequate to drive bipolar logic. The comparator outputs are wired with pull-up resistors (R_{11} - R_{15}) and serve as inputs to a bipolar 32x8 programmable read-only memory (PROM). Four of the eight outputs of this device comprise the decoded Braille signals which change at the rate at which the visual display data is output in the calculator.

The PROM outputs are tied through pull-up resistors (R_{16} - R_{19}). These resistors are needed to pull the output of tri-state TTL gates up to a voltage which will reliably interface with the CMOS devices used throughout most of the interface. The pull-up resistors also allow open collector PROMs to be used instead of those with tri-state outputs. The Harris PROM 8256 device shown is one with open collector outputs.

To display numeric data, the decoded segment drive signals are passed to a six-bit D flip-flop via a quad 2-input multiplexer (Z3). This multiplexer serves to route either sign or numeric output to the hold register (Z4). The contents of the hold register serves to drive remotely located relays modified to raise pins for the tactual output. These relays have drive transistors (Q_1 - Q_4) located near them in the display unit.

The timing to strobe the decoded segment data into the hold registers makes use of buffered timing signals from the printer interface connector of the calculator. Other calculators will usually have similar signals available somewhere in the timing section of the instrument. These signals are directly compatible with 5V CMOS from the SR-52 calculator. The display character clock CkC is used to advance a four-bit counter (Z5a) on the trailing edge. Resistors (R_{24} - R_{25}) are inserted in the line to avoid possible adverse effects on the calculator of having it connected to the interface when the latter's power is turned off. The five volt Zener diode (D1) protects the input gate from over-voltage from static on the connector when not mated with the calculator.

A pulse which occurs at the beginning of each calculator display cycle (CkD) is used to reset the counter as well as to clear other registers. This signal is routed via a level comparator gate (G_6) to reduce stray capacitance loading since it is wired to several points in the circuit. A second counter (Z5b) is clocked on the trailing edge of a locally generated count pulse. This counter serves to control the Braille character display and is advanced at the rate of 1/2 character/sec. to 2 characters/sec. The clock source is a timer (Z6) integrated circuit with fixed off time and user selectable on time. Gates (G_8 - G_9) serve to inhibit clocking or to speed up the timing when blank fields occur in the output.

A four-bit comparator (Z7) detects coincidence between the calculator displayed character and the desired output character time. At coincidence, the A = B output becomes true provided that the A = B input is true as it will be in the run state. A resistor, capacitance pair (R_{28}, C_1) and gate (G_7) serve to delay this transition to insure that the display data has stabilized prior to strobing into the output hold register (Z4).

The decimal drive signal occurs in coincidence with the calculator displayed character with which the decimal point is associated. This signal is routed through a comparator gate (G_{11}) and logical ANDed with the coincidence A = B signal (G_{12}) and then serves to turn on a transistor (Q_5) which directly drives a transistor radio speaker. The resulting speaker drive is a low duty cycle pulse at a rate of about 770 Hz during the time the tactual display is outputting the digit of interest. The speaker audio output is adequate for use of the device in a high noise environment.

The display sequence is initiated by activating a microswitch (SW1) collocated with the tactual display. The switch is activated by the thumb of the right hand while the index finger rests over the display pins. The switch

closure pulls the clock line of a D flip-flop (Z8a) high through a resistor (R_{38}). Once set, an AND gate (G_{13}) is enabled to clock another D flip-flop (Z8b) near the rising edge of the next local timing pulse. The set output of this latter flip-flop signals the run mode. This level enables the comparator (Z7) and allows clocking of the output display counter (Z5b). The output sequence is terminated on the falling edge of the most significant count state of the latter counter (Z5b). The capacitively coupled count state is inverted in an inverting buffer (G_{15}). This gate (type 4049) allows input voltages in excess of the supply voltage and is used here because of the nearly 100% overvoltage which occurs at the input on the rising edge of the count state. The gate output serves to reset the flip-flops (Z8a, Z8b) set as a consequence of the microswitch closure.

A D flip-flop (Z9a) is used to separate the calculator display cycle into two parts. At the beginning of the display cycle, the flip-flop is reset by the CkD pulse. At the end of character display time C_1, this register is clocked by the fast counter state 2 and remains set throughout the remainder of the display cycle. The set and reset sides of the flip-flop serve to directly control the 2 input multiplexer (Z3) and the sign data is routed to the hold register input during character times C_0 and C_1. Thereafter, the decoded segment drive data is routed to the hold register (Z4).

The visual display character clock states are further decoded by multiple input NAND gates and an inverter (G_{16}, G_{17}, G_{18}) and inverted (G_{19}, G_{20}) to identify character display times C_{14} and C_{15}. It is during these times that the sign information occurs on the sign and exponent present line from the calculator. Data on this line results in voltage swings of from -6 to +4 volts. A decoupling resistor (R_{41}) and diode (D2) limit the negative swing to less than one volt. A comparator gate interfaces this signal to the interface voltage

levels. The gate output will be a positive pulse during character time C_{15} if the mantissa sign is negative, and during character time C_{14} if the exponent sign is negative. Whenever the calculator display is in scientific notation, a positive pulse also occurs during character time C_2 and the last 20 µsec. of C_1.

The exponent data is held in D flip-flops (Z10a, Z10b). This is accomplished by clocking the flip-flop with the decoded display character clock states C_{14} or C_{15}. The D input is wired with the sign present line. Since these registers will be updated once every 1.3 msec, no provision is made to clear the flip-flops. The presence of the exponent present pulse (scientific notation) is saved in a D flip-flop (Z9b) by clocking it with the logic AND of the sign and exponent present line and the C_0 or C_1 character time level (Z9a). This flip-flop is reset by the low state of the local timing clock. The low state of this clock also resets the hold register (Z4) so that all Braille indicator pins will drop between outputting successive characters.

The sign data and display format information are output during Braille display times 0 and 1. The minus signs result in Braille dots 3 and 6 being set whereas the plus signs (in scientific notation) are output as an apostrophe (dot 3 only). Braille dots 2 and 5 are always omitted and are therefore wired at the selector to ground. The selector (Z3) acts as a four pole double throw switch and routes the sign data to the hold register during calculator display times C_0 and C_1. The logic equations for the input to the selector are:

$$B_3 = ((DM \cdot \bar{Q}_o) + (DE \cdot Q_o)) + DS$$

$$B_6 = (DM \cdot \bar{Q}_o) + (DE \cdot Q_o)$$

where B_3 and B_6 are Braille dots 3 and 6 respectively, DM and DE are the state of the mantissa and exponent sign hold registers, DS is the state of the

exponent present register, and Q_o is the low order count state of the calculator display character counter (Z5a). These logic equations are implemented by AND and OR gates (G_{23} - G_{26}).

Blank fields in the Braille output are detected by an eight input NOR gate (G_{27}). This gate has as inputs the instantaneously decoded segment or sign data and the output of the hold register. The output of the gate is itself held in this register (Z4) as the result of the coincidence signal. If the previous Braille data in the hold register was not all zeroes, and the new data is all zeroes, or some non-zero code, the NOR gate output will not be true at the moment the hold register is clocked and a low level will be saved. When both the old and new data are zeroes, a high level will be observed at the output of the NOR gate (G_{27}).

The state of the held comparison routes either the local oscillator signal or the CkD signal to the output display position counter (Z5b). This routing is via AND and OR gates (G_{28}, G_9) which effectively implements a two input, one bit multiplexer. The result of the detection of two successive blanks is that the output display counter (Z5b) is quickly advanced to the next state.

3. Interface Imposed Restrictions to Use of the Calculator

While the SR-52 to Braille interface properly accounts for signs, decimal place indication, and either floating point or scientific notation, some peculiarities will occur in the Braille output under certain conditions. The user of the Braille output should be aware of these situations and the way to interpret the result or to avoid anomalous situations.

Whenever a full ten digit number less than unity is generated as the result of a computation, as for example when dividing one by three, the Braille output will appear as if there were an eight left of the decimal place. This is the result of data on segment drive lines which are normally not visible. To avoid this problem, use the fix key to exercise display control which restricts the number of digits output. By restricting the number of mantissa digits to nine or fewer, the result of this computation will be properly displayed with a leading zero with which the decimal position is associated.

When numbers are entered with no decimal point, they will be displayed with the decimal point associated with the exponent sign. In floating point notation, the audio output will be very brief, and in scientific notation the audible decimal indication will occur during the output of the exponent sign. This situation will never occur if a decimal point is entered or when a number results from any computation.

Computational errors are indicated on the SR-52 by a blinking display. The resulting Braille display will be jittered to some extent but this will depend on the relationship of the Braille output rate and the rate of display blinking. It may be necessary to initiate another display cycle to verify that the display is blinking, but this situation will usually be apparent to the user.

Certain computations may take a long time to complete and the visual display is blanked at this time. The Braille output will also consist of all blanks and will therefore result in a very quick display cycle with no pins being raised. Reinitiating a display cycle a few seconds later will allow the user to determine when the processing is completed.

Acknowledgment

The author acknowledges the support of the Naval Air Systems Command under which contract the components were procured and the printed circuits fabricated.

In addition, the assistance of T. R. Pryde is recognized. It was he who made the necessary wiring revisions to the calculator and who designed and fabricated the calculator cradle. His attention to detail and care in executing the work were outstanding.

Mr. T. H. Martin from New Concord, Ohio, designed and built the tactual output unit, and his contribution in this area was vital to the success of this design. His assistance is gratefully acknowledged.

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